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LIFE TESTS OF TUNGSTEN AND TANTALUM FILAMENTS IN ION GAUGES

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LIFE TESTS OF TUNGSTEN AND TANTALUM FILAMENTS IN ION GAUGES

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Purpose

This paper presents the results of an investigation carried on for the following purposes:

1. To determine the relative life of filaments when operated at low emission (low temperatures) as compared to those operated at high emission values.
2. To determine the nature of the dependence of life upon the initial diameter of the filament.
3. To determine the effect of varying concentrations of water vapor and air upon the life of the filaments.
4. To determine the relative life characteristics of tantalum as compared to tungsten.

Method

A large tank (1180 liters) equipped with a suitable vacuum system was arranged to mount seven ion gauges. A leak was prepared to independently admit air or water vapor or both into the tank.

The gauges used for pressure determinations were calibrated for air by the rate of rise method. Calibration of the gauges for water vapor was accomplished by opening a water leak of considerable size (after a good vacuum had been obtained) and maintaining a trap between the gauge and the tank at the temperature of solid CO_2 (dry ice). This gives a water pressure in the gauge which is that of water at the solid CO_2 temperature, namely 0.50 microns. (This value varies slightly with the barometric pressure, for the CO_2 point is $-78.51°C$ at 760 mm Hg. Tables may be consulted to find the vapor pressure of water at temperatures corresponding to different pressures on the CO_2.)

Gauges to be tested were put on the tank and pumped out for some time before being operated. Then, under high vacuum, they were turned on and allowed to out-gas for an hour or so. (This latter procedure was not followed in the case of tantalum, since outgassing took but a very few minutes.)

The time during the rate of rise experiment was then counted from the instant the leaks were opened.

An occasional check of the relative air to water vapor ratio was made by putting liquid air on the traps to eliminate the water. In the case of the tungsten filaments, a coiled filament 10 cm long was used (except in tests of tetrode-type gauges, in which case it was 6 cm long and coiled), while in the cases of the tantalum a hairpin filament 3.8 cm long was used in a Distillation Products Type VG-1A gauge.

The grid voltage was approximately 130 volts and the plate voltage was -22 volts in all cases.

A total of 18 filaments was tested, 7 of these being tungsten and the rest tantalum.

Discussion

Figure 1 presents the life history of four of the tungsten filaments, started all at the same time and under identical circumstance except as noted. Numbers 1, 2, and 3 were 10 mil diameter coiled filaments, while No. 4 was a 15 mil coil. Until Nos. 1, 2 and 3 failed, and for some time afterward, the atmosphere was held constant at a pressure equal to 1 micron of water plus 1 micron of air. At first, some difficulty was experienced in doing this and a scattering of points resulted, as is shown in Fig. 1. However, this was repeated with gauges No. 5 and No. 6, this time with well regulated control throughout the experiment. The results are nearly identical to those presented on Figure 1.

As time went on, it was apparent that the low emission (0.010 ma) filament was becoming considerably tapered in dimension, so when the tests were finally finished the remains were carefully saved and measured with a micrometer. The results of these measurements are shown in Figure 2. It will be noted that only in the very low emission tube did tapering seriously enter into the destruction of the filament. This tube, operating at an emission 1/500 that of the hottest one, started at a lower wattage input and ran to very nearly zero, the last readings being well below one watt.

It is well to note that during the tapering of filament No. 1, the calibration did not materially change.

From tube No. 4 on Figure 1 (which has not yet failed after some 90 hours and retains about a 2 mil filament), it can be seen that the decay rate responds immediately to changes in concentration of air and water vapor. Tubes Nos. 5 and 6 show this same phenomena, as do Figures 4, 5, and 6. They also indicate that there is nearly a threshold concentration value (around 2×10^{-4} mm Hg) for water below which decay is very slow. This may also be true in the case of air.

Further, it seems true that this threshold decreases as the operating temperature is lowered. This is again shown in all of the decay curves for tantalum and tungsten, for in all cases excepting one of eighteen, the life is longer as the emission is increased. This may be due to the fact that though the gauge pressure is more or less the same in each case, the higher the temperature, the lower the gaseous concentration.

It seemed surprising that the power required for a given emission is a linear function of the time as long as the conditions are constant, but all cases indicate this is true for tungsten. No linear relationships were found for tantalum.

The surmise was made that in the case of tungsten (if we assume no poisoning or activating) the power for a given emission is constant for a given area and a decrease in power means a decrease in radius. To check this, the filaments of gauges Nos. 1, 2, and 3 were measured and the results compared with those computed for the ratio of final to initial power. These results are here shown:

Tube	Measured Diameter	Calculated
1	0.0017 (from R)	0.0025 " (from R)
2	0.0021	0.00228 "
3	0.0047	0.00508 "

This indicates that if tapering is not serious, the relation is essentially true.

The case of tantalum presented unexpected results inasmuch as it was reported to be superior in performance to tungsten. For this reason observations on the first pair of tubes was inadequate, as is shown in Figure 8. Also in this case, coiled filaments were used similar to the tungsten ones. Failure seemed to be due to sagging and consequently hairpin filaments were adopted for later tests. Subsequent results, however, indicate that the sagging was merely incidental with burnout.

The results of the several tests made may be summarized by the following table:

Tube	Atmosphere	Emission	Life
No. 7 (coiled fil 10 mil)	1 air + 1 H_2O	0.5 ma	1 hr. 50 min.
No. 8 (coiled fil 10 mil)	1 air + 1 H_2O	5.0 ma	2 hrs. 30 min.
Tetrode tube No. 9A (coiled fil 20 mil)	1 air + 1 H_2O	0.5 ma	2 hrs. 44 min.
No. 10 hairpin 10 mil	1 air + 1 H_2O	0.5 ma	1 hr. 50 min.
No. 11 hairpin 10 mil	1 air + 1 H_2O	5.0 ma	2 hrs. 0.4 min.
No. 12 hairpin 10 mil	1 air + 1 H_2O	0.5 ma	2 hrs. 39 min.
No. 13 hairpin 10 mil	1 H_2O	5.0 ma	2 hrs. 55 min.
No. 15 hairpin 10 mil	1 H_2O	0.5 ma	6 hrs. 48 min.
No. 16 hairpin 10 mil	1 air	5.0 ma	7 hrs. 21 min.
No. 17 hairpin 10 mil	1 H_2O	0.5 ma	3 hrs. 18 min.
No. 18 hairpin 10 mil	1 H_2O	5.0 ma	3 hrs. 26 min.

The most noticeable characteristic of the tantalum filaments was their irregular behavior as compared to that of the tungsten. At burnout the sketches (Figure 7) illustrate typical appearance. The whole filament mass seems to become sponge-like and quite irregular in size. This has been observed in other cases of the use of tantalum for filaments. This swelling, resulting in increased surface, is reflected in the sometimes rather continuous increase required in wattage. Different individual filaments showed different properties so far as details were concerned, but the life seemed to be more or less specifically determined by the emission and the atmosphere.

With tantalum, as in the case of tungsten, somewhat better life results at high rather than low temperatures. Gauge No. 18 disproved this rule.

During the experiments, reports from F. R. Elder of the General Electric Company indicated that very long life was being obtained from tantalum with an "atmosphere of water at 1 micron". Since this in no way checked the results herein obtained, an analysis was requested of the wire being used here. Also, the G. E. Research Lab. sent a sample of the 10 mil Ta that they were using. Gauges #17 and #18 were constructed from this wire (which also is undergoing analysis); so far, no report has been made concerning these determinations. However, since the results obtained with the G. E. sample are very similar to those of the previously used filaments under similar conditions (#12 and #13), the assumption seems good that both samples actually are tantalum. The wattage behavior of the two samples is different, but the life is essentially the same.

Conclusions

From the foregoing it would seem that the following several conclusions are justified.

1. For the concentrations of air and water vapor tried, there is no advantage to be gained in operating tungsten filaments at excessively low emissions in order to reduce the temperature. This seems likely for tantalum also.
2. In the case of tungsten, the wattage required for a given emission is a linear function of the time of operation, and the ratio of the final to the initial power is the same as the ratio of the final to the initial diameters of the filaments.
3. Tapering of tungsten filaments at usual emission values is negligible.
4. The life of a tungsten filament is proportional to the initial diameter.
5. No great changes (more than 10%) of calibration were noted during the life of any filament excepting in tantalum a few minutes before burnout.
6. As already known, filament disintegration is in a way proportional to the concentration of either air or water, the water being more effective. This seems to be true of tantalum as well as tungsten.
7. Tantalum filaments of size equal to tungsten filaments can be expected to have from 5 to 10% the life of tungsten in the same atmosphere of air and water.

Further Remarks

Gauges Nos. 9, 9A, and 14 were tetrodes. These showed no particular variation in characteristics over the triode design. However, the tests made were all at constant emission, the emission being controlled by the filament current rather than the control grid. This nullifies any possible conclusion that might be drawn about them.

In the case of large filaments, a large amount of deposited material must be allowed for. This means adequate shielding but such is easily furnished, the VG-1A and others being satisfactory in this respect.

It might also be noted that low temperatures increase the sensitivity of the gauges. Thus, for example, the gauges when run at 0.010 ma were about 25% more sensitive (positive ions per electron) than the same tube run at 5 ma. This is most likely due to alteration of inter-electrode gas concentration as a result of difference in temperature.

Further work should be done to obtain more quantitative measures of probable life in the atmospheres described and also in chlorine and combinations of chlorine, water, and air.

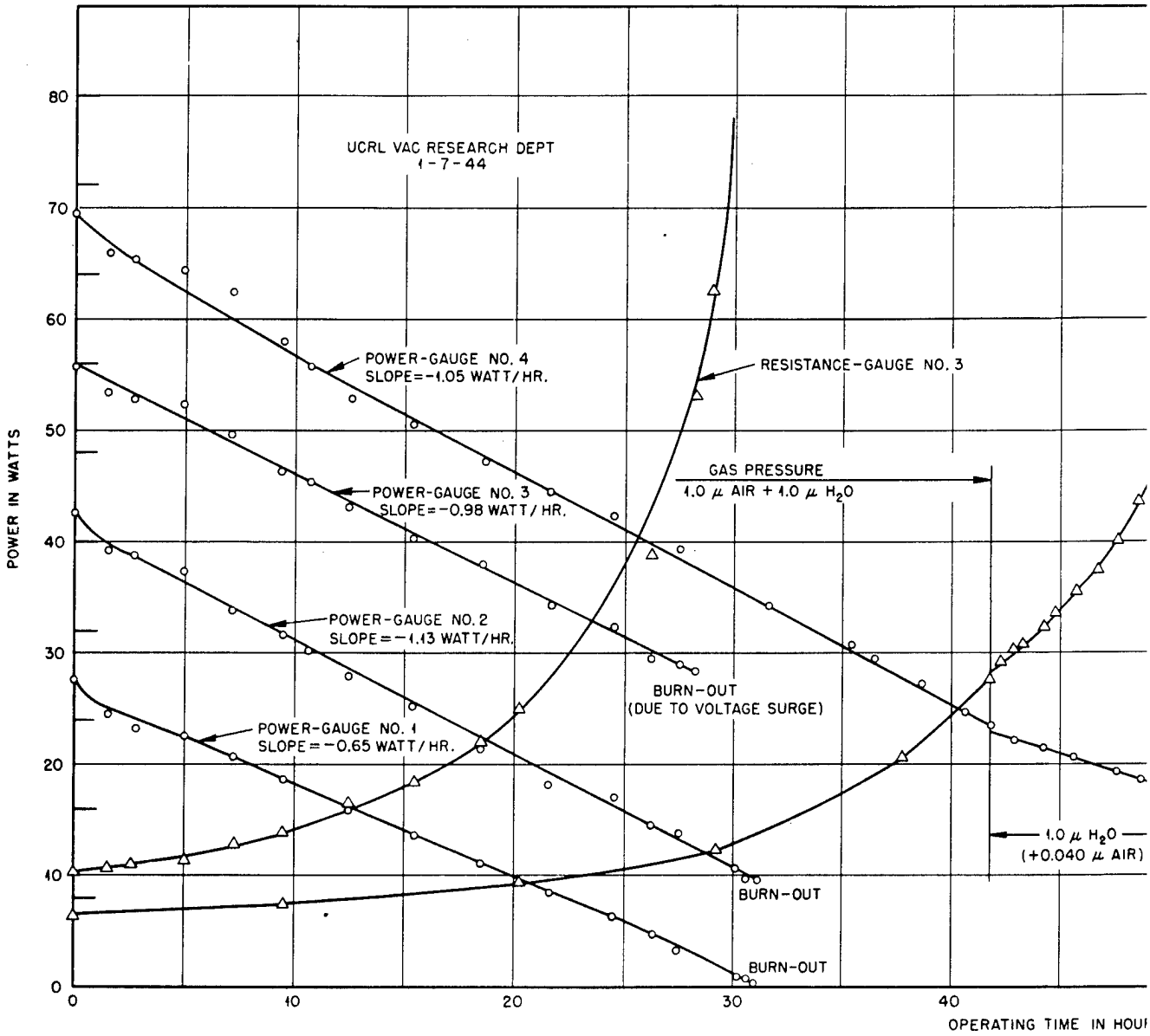
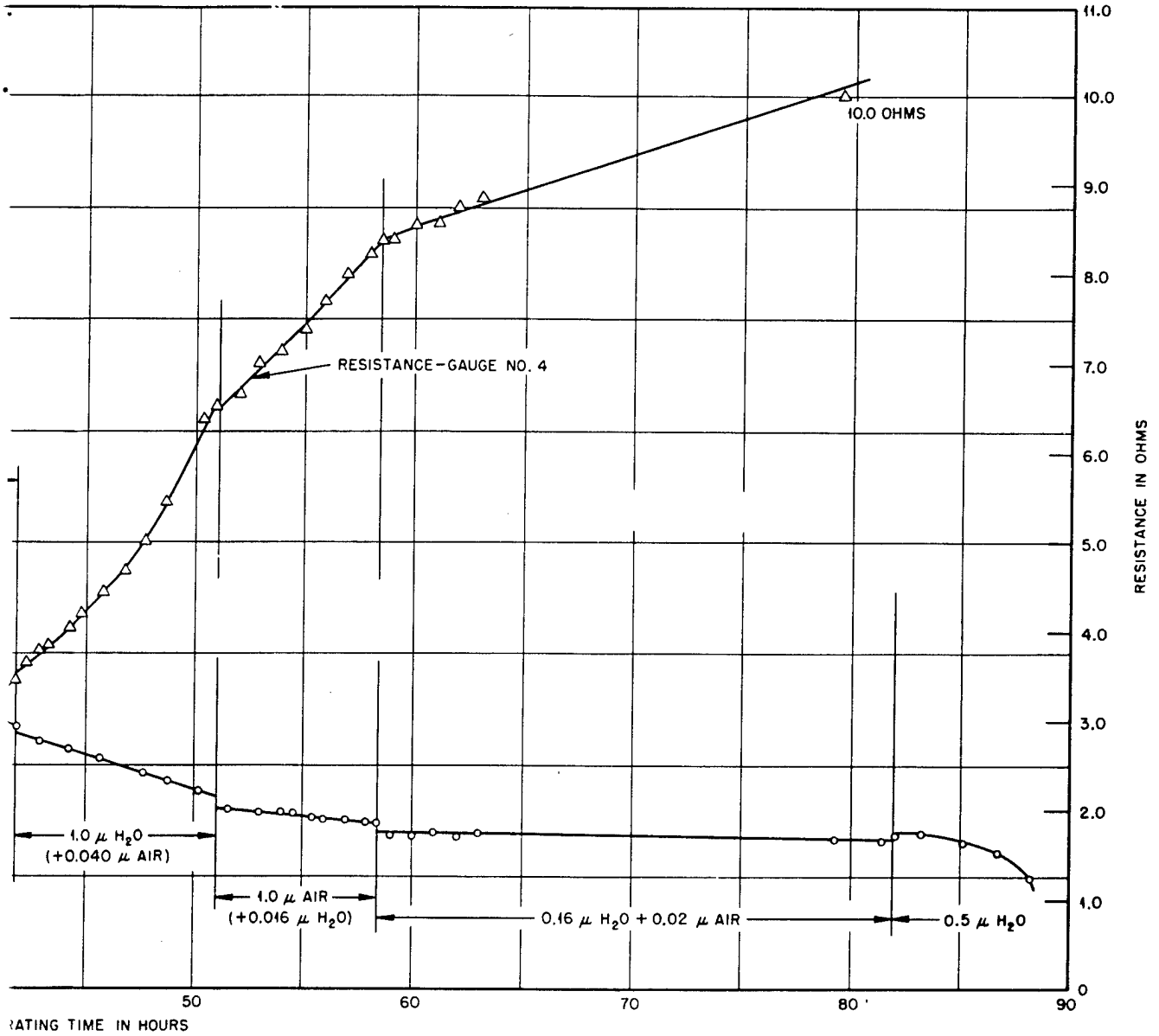


Figure 1. Tungsten Filaments in air and water vapor. Power consumption—resistance as functior

Filament Specifications		Operation		Ep
1. Length:	10 cm.	Gauge 1	Emission 0.010 ma	−22V
2. Form:	8 turn coil	Gauge 2	Emission 0.50 ma	−22V
3. Size:	Gauges 1, 2, and 3: 10 mil; gauge 4: 15 mil	Gauge 3	Emission 5.00 ma	−22V
		Gauge 4	Emission 0.50 ma	−22V



stance as functions of (1) emission (temperature); (2) gas concentration; (3) original filament size.

	Ep	Eg
) ma	−22V	128V
ma	−22V	128V
ma	−22V	128V
ma	−22V	128V

Concentration of Gases

Time		Concentration	
From	To	Air	Water
0 hrs 00 min	41 hr 40 min	1.0 μ	1.0 μ
41 hr 40 min	51 hr 00 min	0.035 μ	1.0 μ
51 hr 00 min	58 hr 20 min	1.0 μ	0.016 μ
58 hr 20 min	81 hr 55 min	0.04 μ	0.16 μ

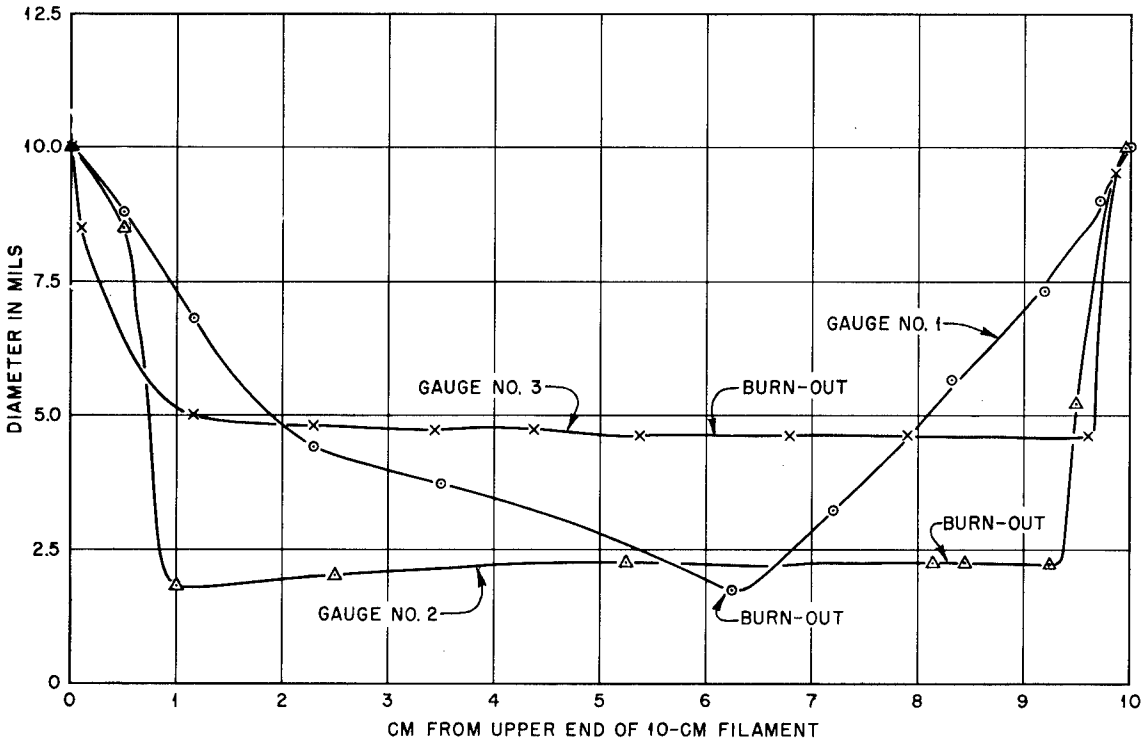


Figure 2. Tapering of tungsten filaments. Coiled (8 turn) 10 mil filaments at various emissions used until failure in an atmosphere of 1 μ air + 1 μ H_2O. No. 1 = emission 0.010 ma; No. 2 = emission 0.50 ma; No. 3 = emission 5.0 ma. Note: # 3 failed as result of voltage surge.

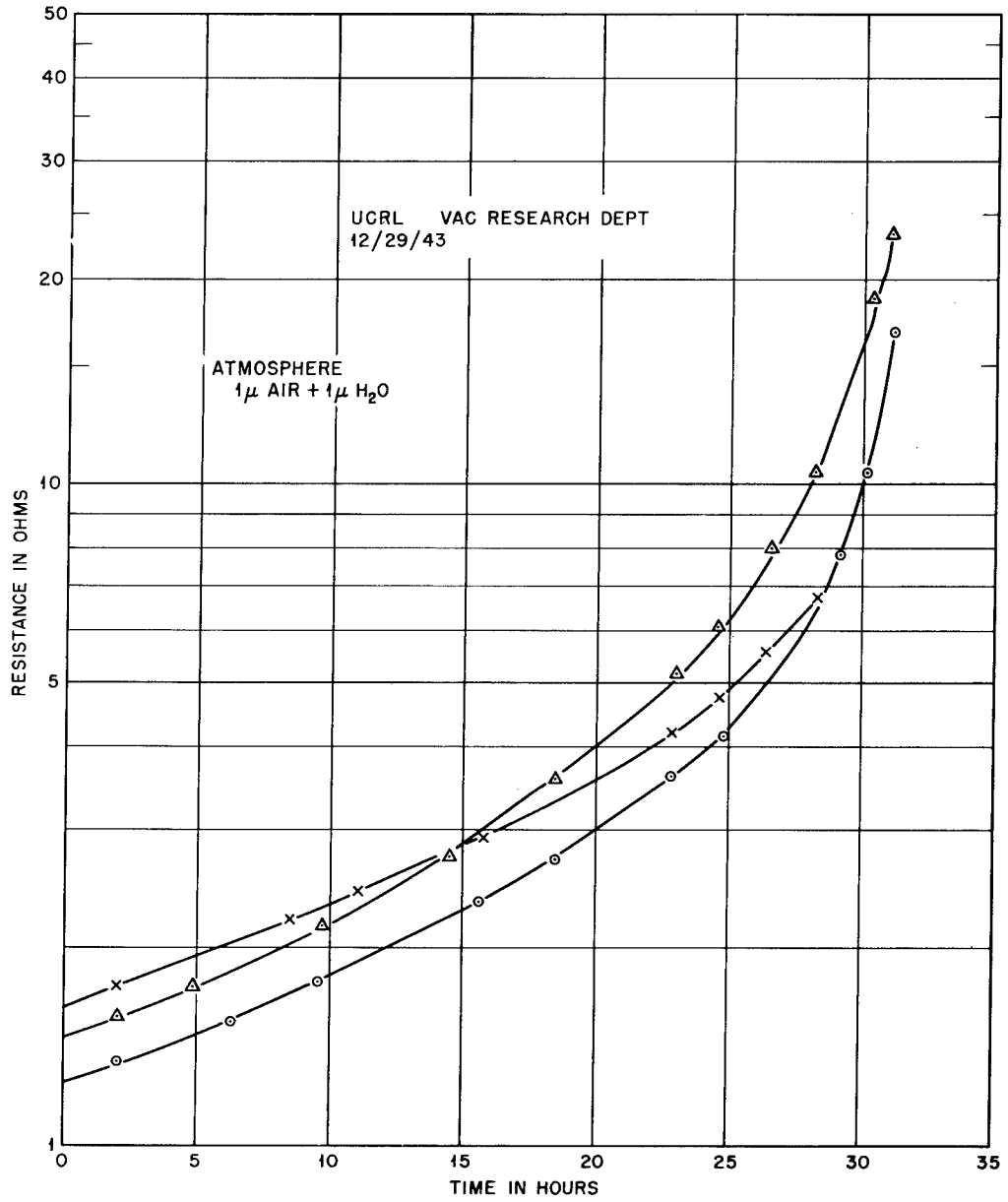


Figure 3. Resistance of tungsten filaments 10 mil, 10 cm long. ⊙ = No. 1 emission 0.010 ma; △ = No. 2 emission 0.50 ma; × = No. 3 emission 5.0 ma.

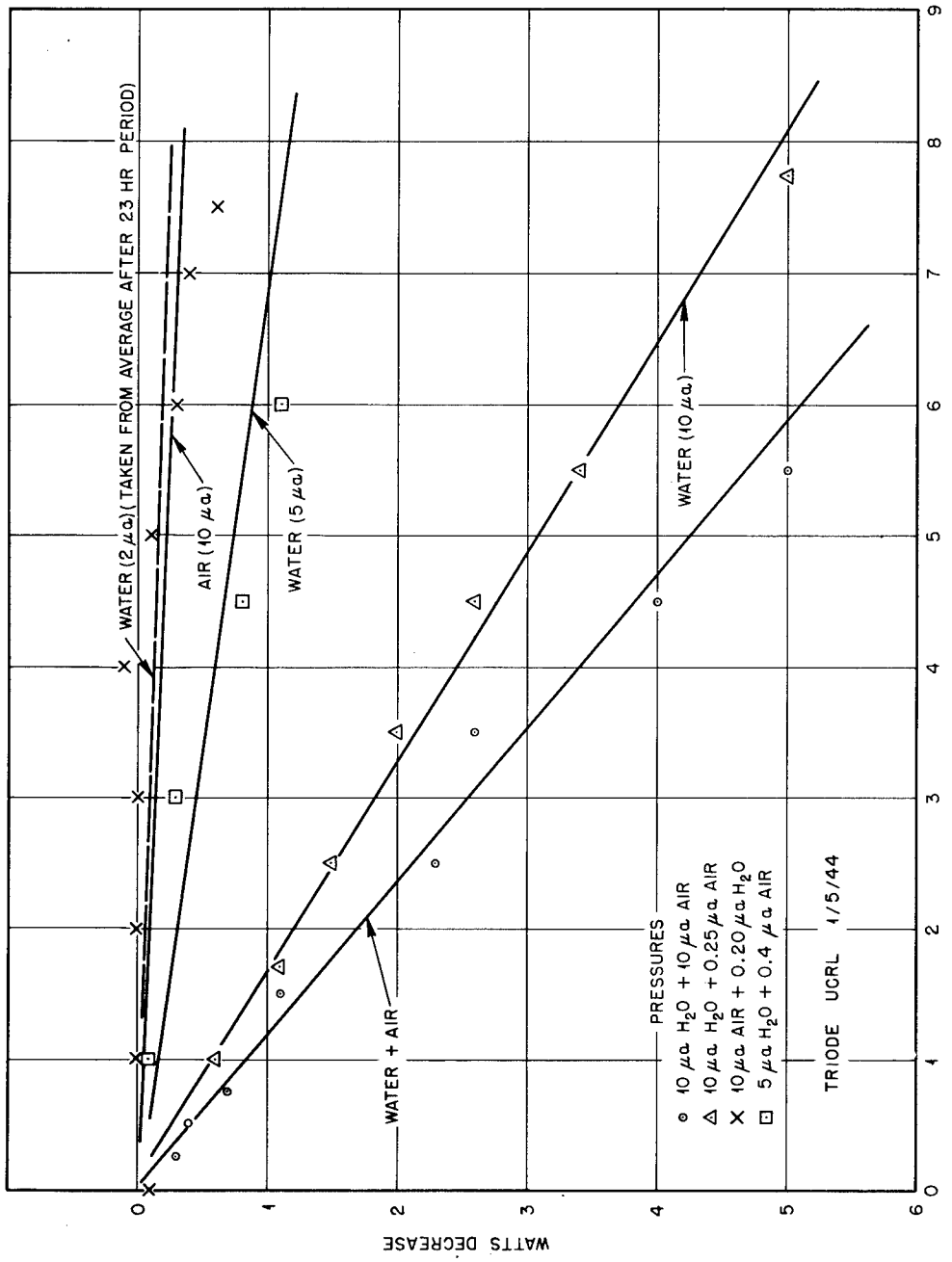


Figure 4. Ion gauge No. 5. Tungsten filament 10 mil, 10 cm long. Emission 0.5 ma; Eg = 130 volts; Ep = −23 volts.

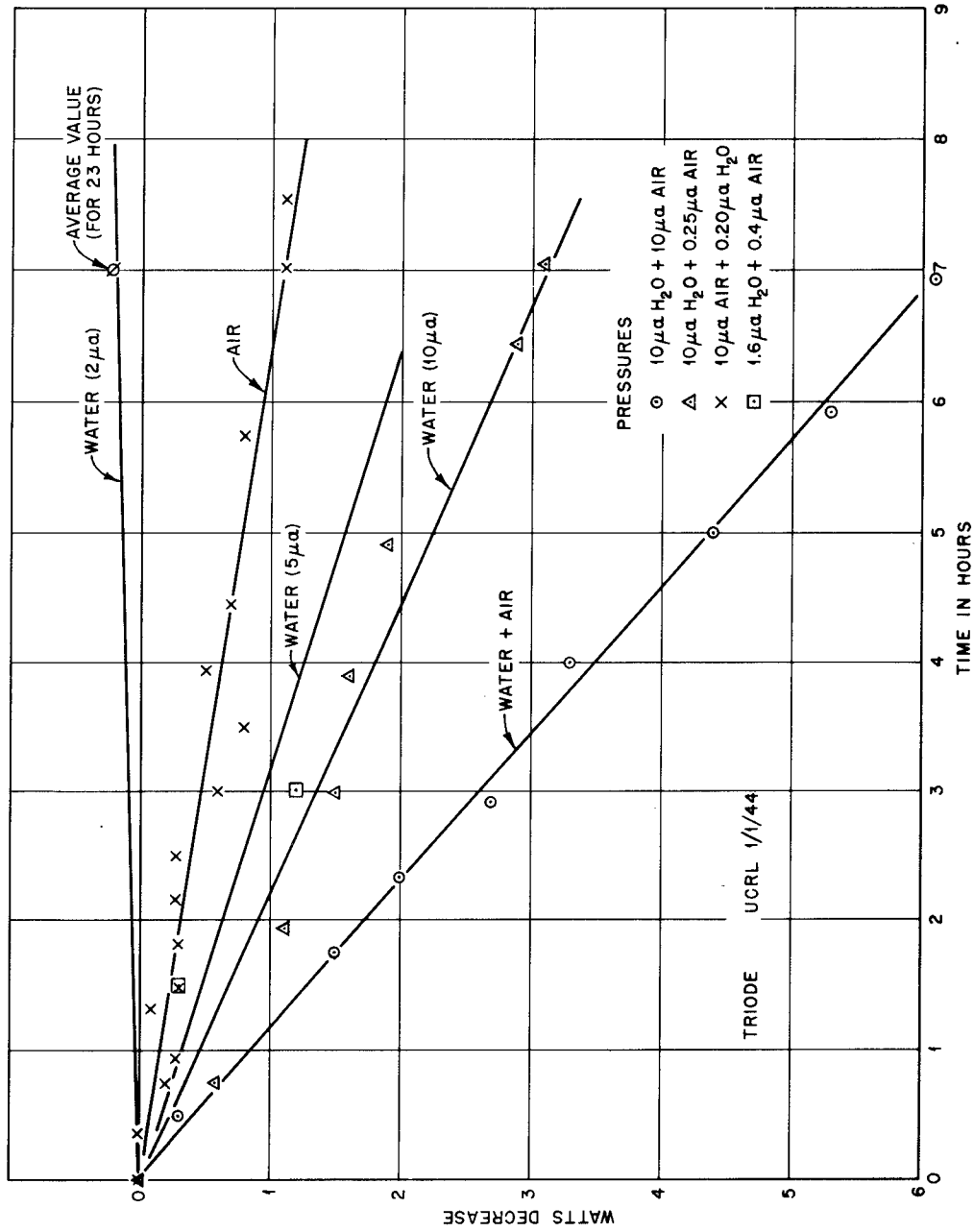


Figure 5. Ion gauge No. 6. Tungsten filament 10 mil, 10 cm long. Emission 5.0 ma; Eg = 130 volts; Ep = −23 volts.

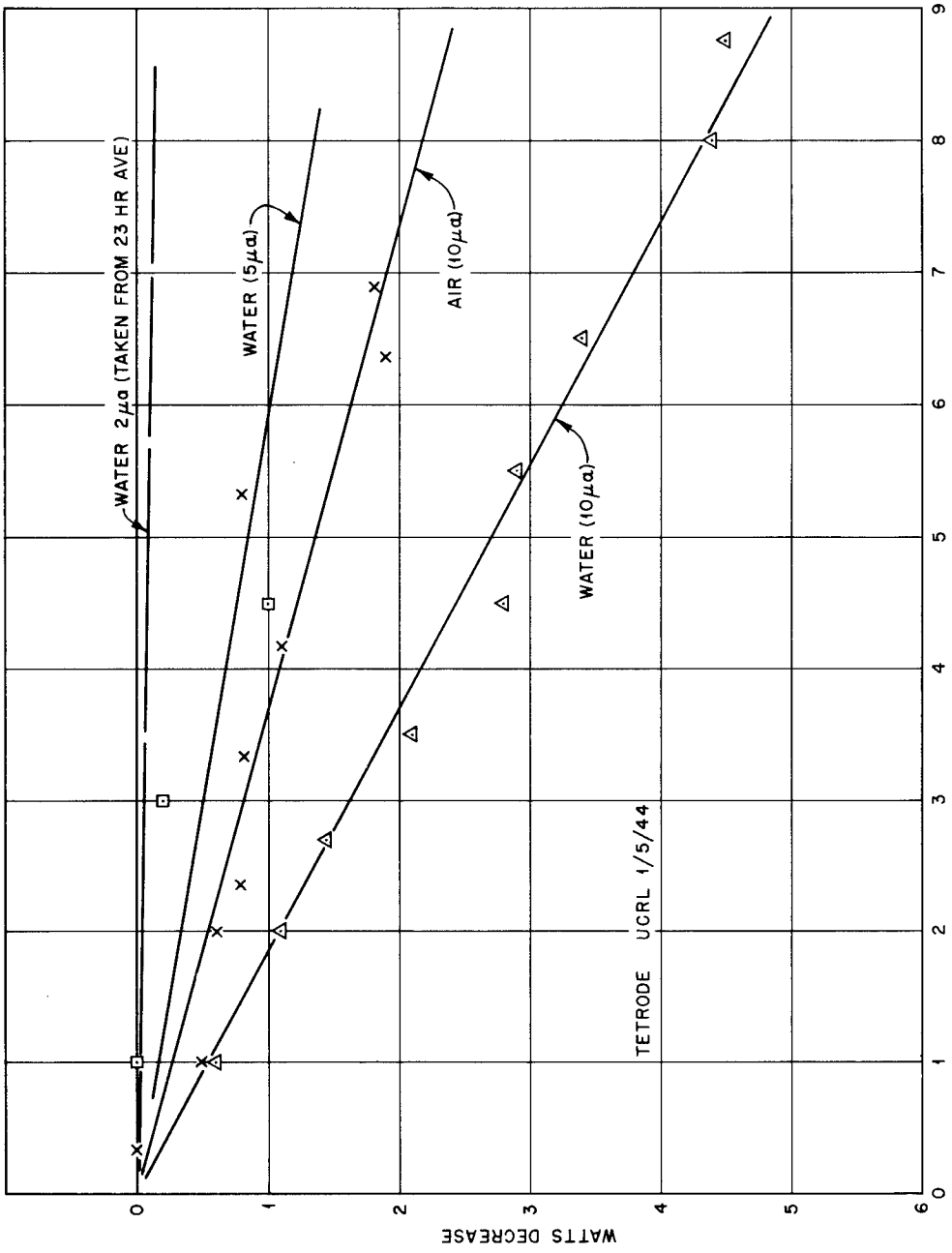


Figure 6. Ion gauge No. 14. Tungsten filament 10 mil, 6 cm long. Emission 0.5 ma; Eg = 130 volts.

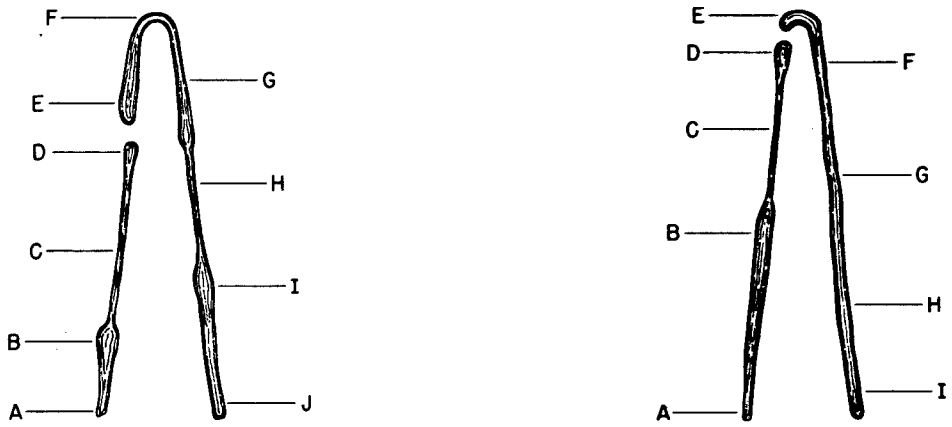


Figure 7. Tantalum filaments.

Filament No. 10	Filament No. 11
A - 0.0098" Dia.	A - 0.0103" Dia.
B - 0.0143 "	B - 0.0123 "
C - 0.0072 "	C - 0.0052 "
D - 0.0119 "	D - 0.0123 "
E - 0.0151 "	E - 0.0142 "
F - 0.0111 "	F - 0.0088 "
G - 0.0135 "	G - 0.0097 "
H - 0.0072 "	H - 0.0124 "
I - 0.0135 "	I - 0.0108 "
J - 0.0103 "	

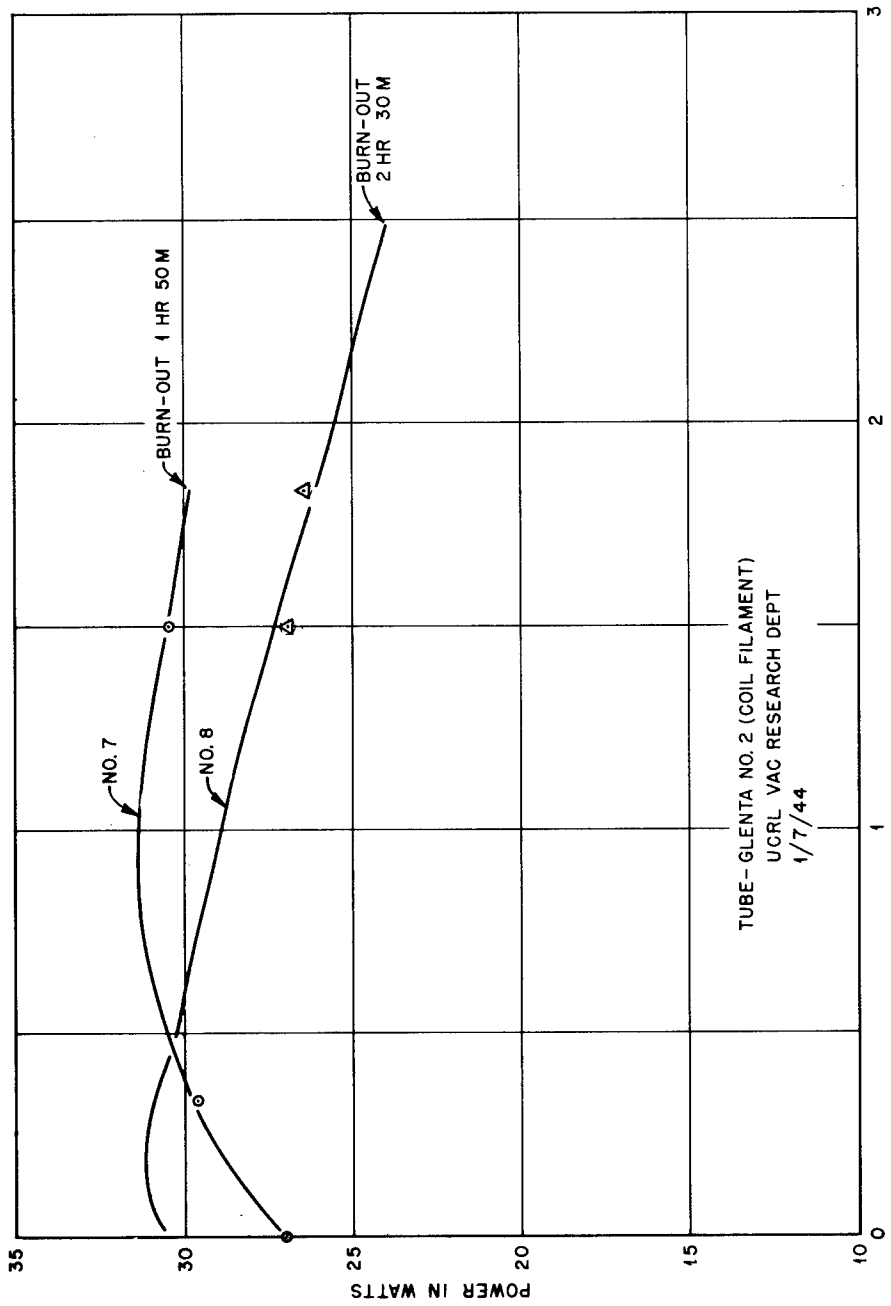


Figure 8. Tantalum filaments. 10 mil, 10 cm long. ⊙ Gauge No. 7; △ Gauge No. 8. Gauge No. 7 at 0.5 ma; gauge No. 8 at 5.0 ma; pressure 10 μa H_2O + 10 μa air.

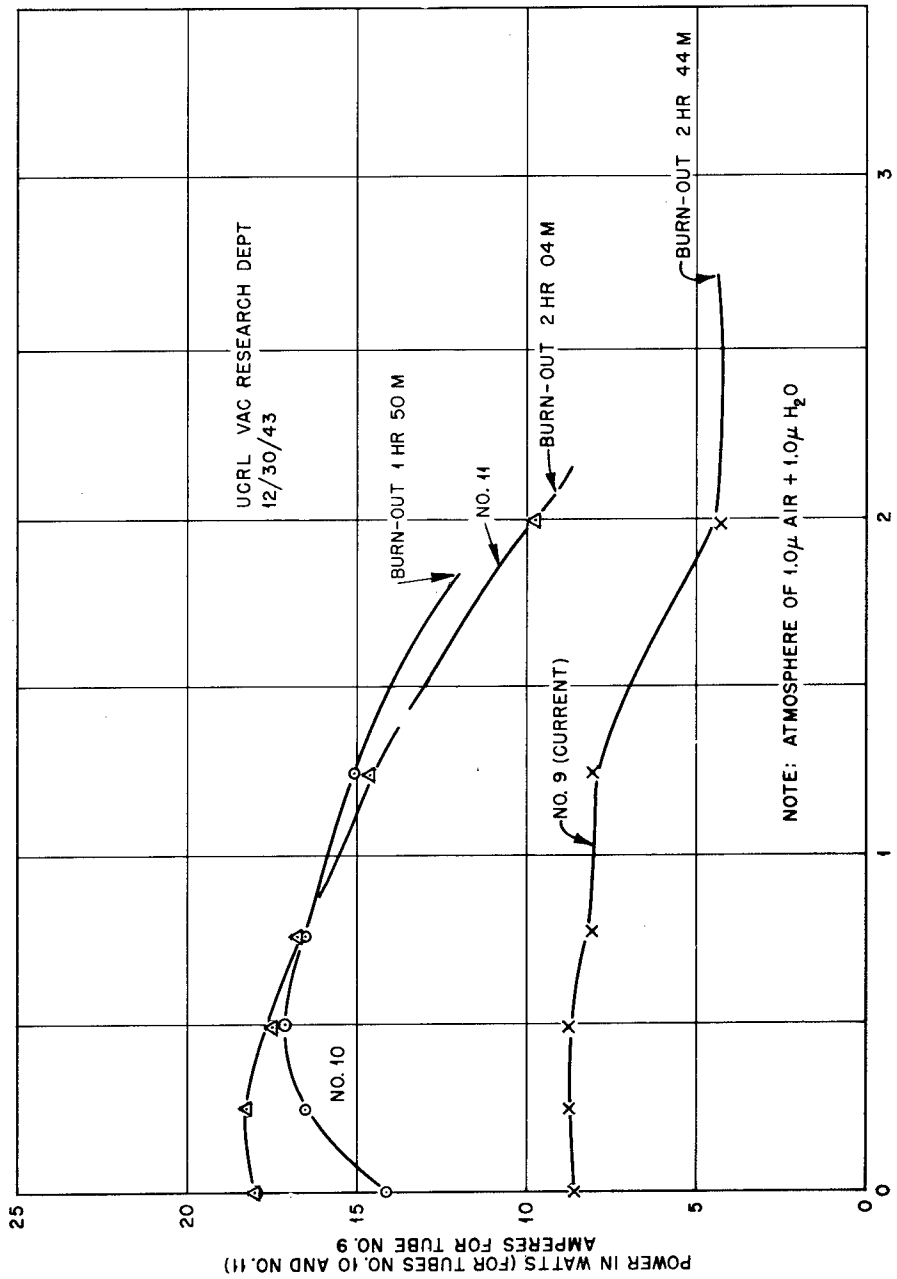


Figure 9. Tantalum filaments. Tube VG-1A (No. 10 and No. 11 only) 10 mil, 3.8 cm long. ⊙ Gauge No. 10, 0.5 ma emission; △ Gauge No. 11, 5.0 ma emission; ×Gauge 9A, 0.5 ma emission. Note: No. 9 is a tetrode designed by Frank Kirby. Filament 6 cm, 20 mil Ta.

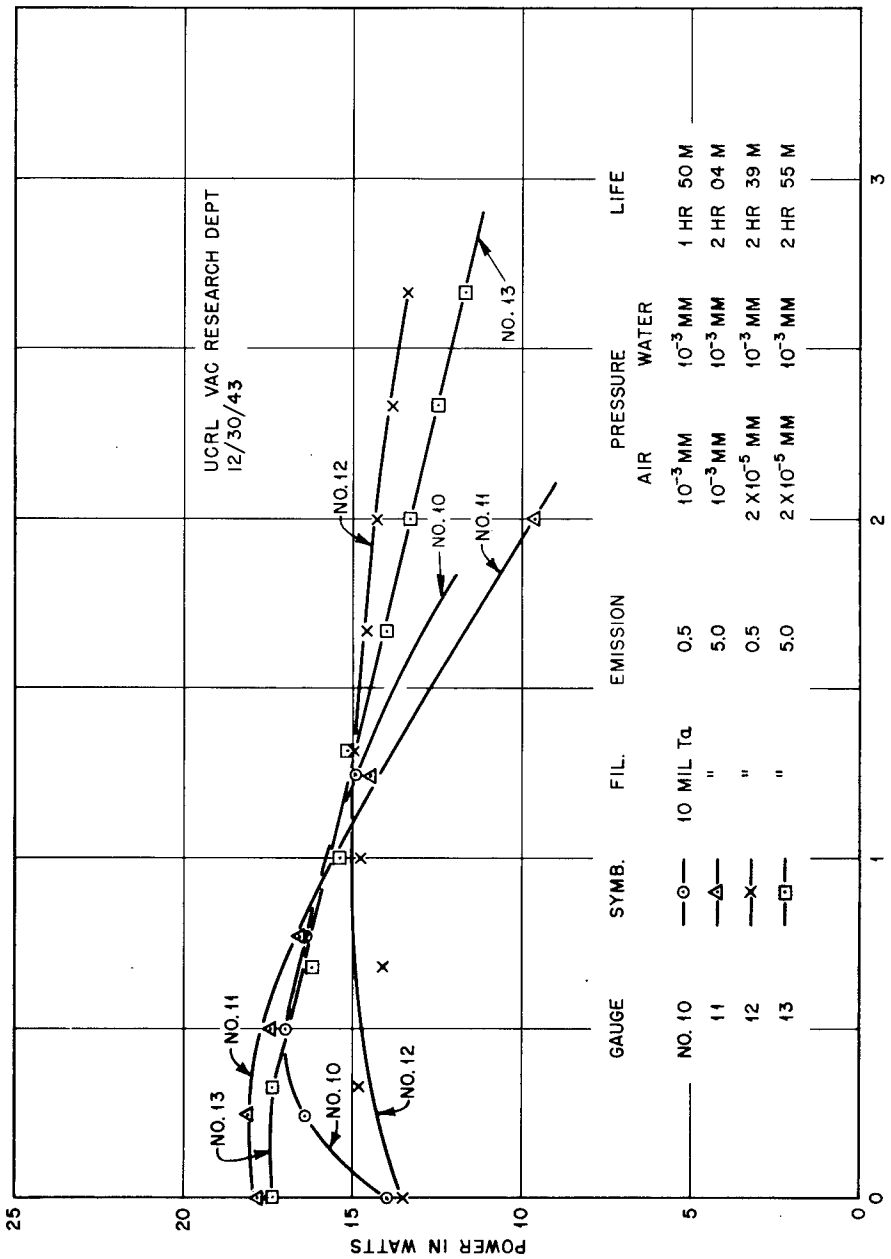


Figure 10. Life tests of four tantalum filaments. Tube used: DPI-VG-1A. Filament length = 3.8 cm; Ep = −23 volts; Eg = 130 volts.

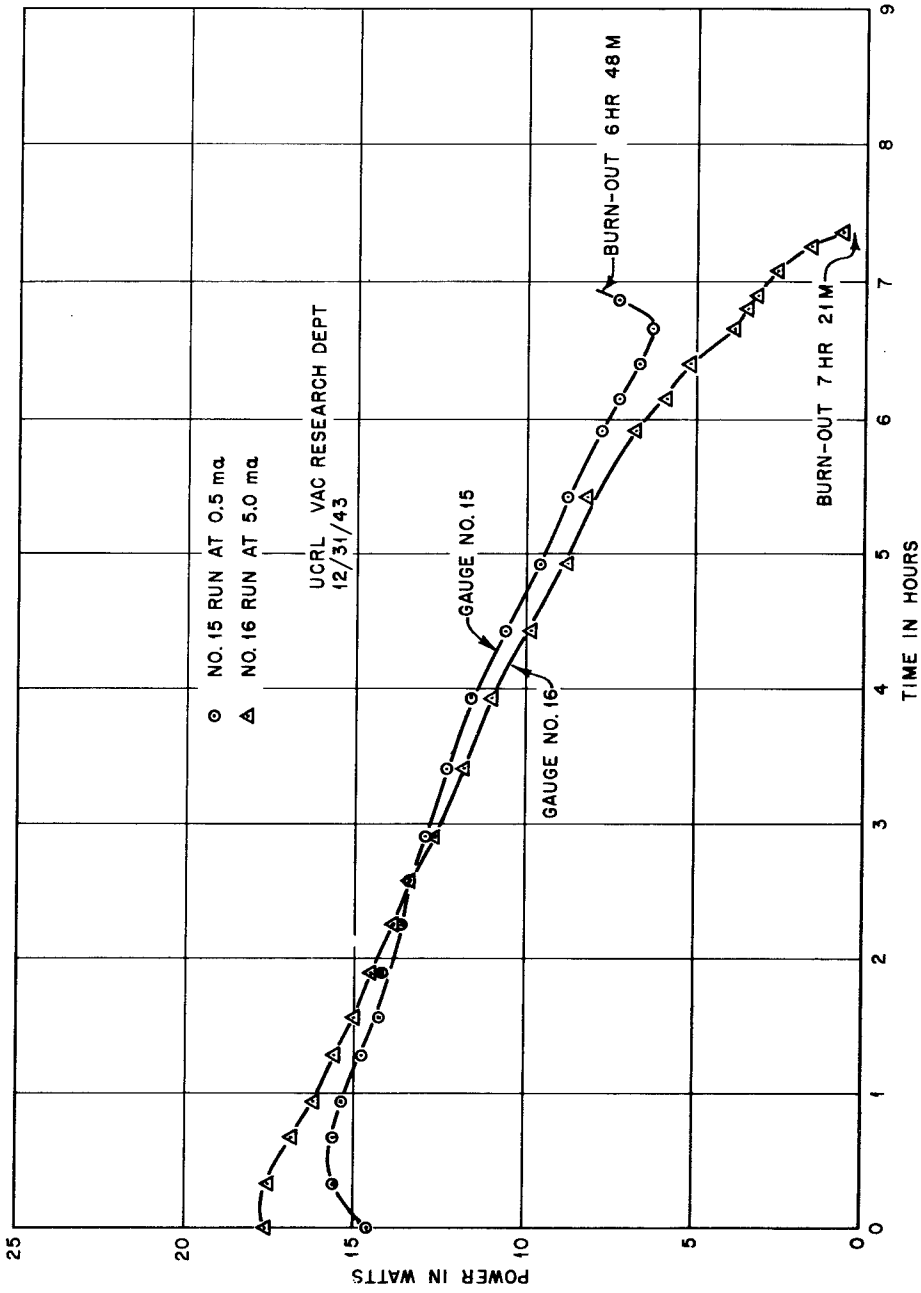


Figure 11. Tantalum filaments. Tube VG-1A: 10 mil Ta, 3.8 cm long in atmosphere of 10 μa air.

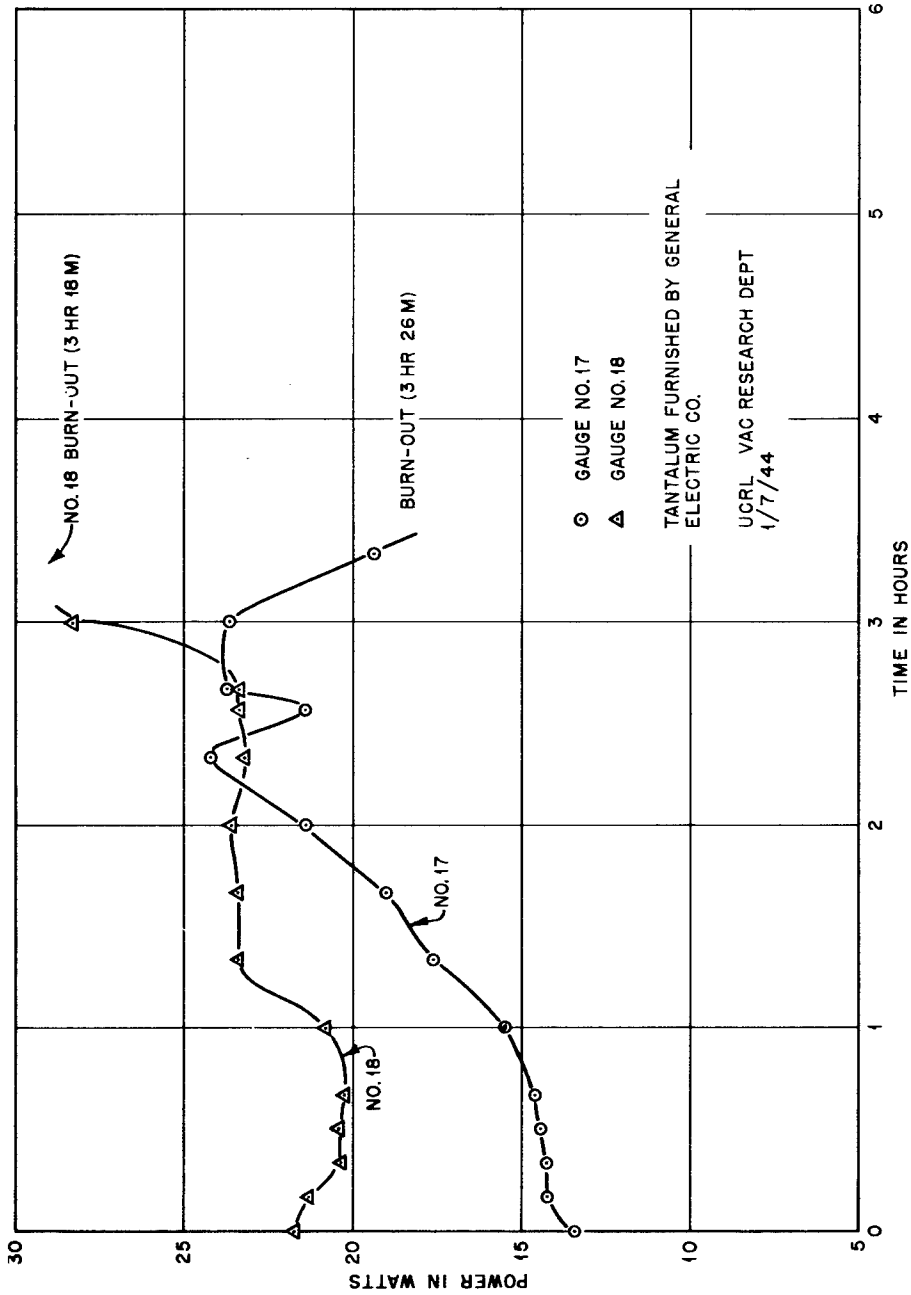


Figure 12. Tantalum filaments. Tube VG-1A: 10 mil, 3.8 cm long. Gauge No. 17 at 0.5 ma. Gauge No. 18 at 5.0 ma. Pressure: 10 μa H_2O + 0.4 μa air.

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